CHAPTER 10

English Theories of Hearing in the Seventeenth Century

Penelope Gouk

English theories of hearing from the seventeenth century have scarcely been studied; perhaps a major reason is that by comparison with their contemporaries on the Continent, English writers contributed little that was original to the stock of facts or interpretations concerning hearing. Nevertheless, the way they responded to their continental sources, both ancient and modern, and especially the way their approach to the subject was affected by Descartes's great synthesis of natural philosophy, sheds valuable light on the evolution of English thought during a crucial period.

Hearing was actually an important concern of the seventeenth-century English intellectual tradition, but its significance has been obscured because it was not treated as a unified subject, nor was any book ever devoted to it. Instead, theories of hearing were integrated with a variety of discrete topics in seventeenth-century English thought. Among these are works dealing with sensory phenomena and the organs of sense; medico-religious texts concerned with the relationship between the soul and the body; anatomical and medical texts which examine the structure and function of the parts of the body; works on natural philosophy and natural magic, dealing with theories of matter and cosmology and with the operations of nature; writings on education, politics, philosophy and music. Seventeenth-century categories of thought are quite independent of present-day ones, and we must not expect to find the kind of systematic treatment that would be adopted by a modern writer.

Despite the kaleidoscopic variety of sources just outlined, a small range of shared concerns emerges from the literature. Not every writer treated all of these issues, but on the whole English discussions of hearing focused on five topics. Two of these, how sound is propagated and how musical consonance is generated, are also found independently from the question of hearing itself; the others are more directly related. These are: how sound is received by the ear and brain; how it affects the mind, soul or body; and how it is retained in the memory. Such concerns bridge the modern categories of acoustics, perception, psychology and so forth, and are clearly not quite equivalent with them.

English ideas on hearing in the seventeenth century drew extensively on classical and recent continental sources. Among the ancient authorities, the Aristotelian corpus was fundamental. Galen stands out as a source for the therapeutic power of music. The Platonic tradition, both directly and as filtered through Italian Renaissance Neoplatonism, was also important.[1] Continental

Abridged from Penelope Gouk, "Some English Theories of Hearing in the Seventeenth Century: Before and after Descartes," in Charles Burnett, Michael Fend, and Penelope Gouk, eds., *The Second Sense: Studies in Hearing and Musical Judgement from Antiquity to the Seventeenth Century* (London: The Warburg Institute, 1991), 95–113.

writers whose work informed English seventeenth-century thought included anatomists such as Bartolomeo Eustachio and Giulio Casserio, humanists such as Girolamo Fracastoro and J. C. Scaliger, natural philosophers like Marin Mersenne and René Descartes, and many others. The Cartesian synthesis knitted together threads from numerous existing intellectual traditions rather than offering an original understanding of hearing; nevertheless, it radically altered the terms of discourse from the middle of the century.

This is illustrated by the six writers whose works will be discussed here. They fall into two chronological groups of three. Francis Bacon (1561–1626), Thomas Wright (1561–1623) and Helkiah Crooke (1576–1635) were contemporaries who all published their work in the first quarter of the century and were virtually the only English authors who wrote a substantial amount on hearing in this pre-Cartesian period. Kenelm Digby (1603–65), Thomas Willis (1621–75) and Robert Hooke (1635–1703) produced their theories roughly in the third quarter. Although there were by this time others who wrote extensively and interestingly on matters related to hearing, most notably Walter Charleton and Isaac Newton, these three have been selected for their correspondences with the earlier group: Bacon and Hooke are known for their experimental approach to learning; Crooke and Willis were anatomists; Wright and Digby were primarily occupied with religious concerns. Furthermore, the reactions of Digby, Willis and Hooke to Descartes are especially illuminating.

The change in patterns of education that had taken place in England during the sixteenth century meant that an Elizabethan gentleman was likely to be familiar with learned books and to have spent some time travelling on the Continent. . . . Whether or not it was through their travels that all three became acquainted with continental literature, there is no doubt from their writings that they were deeply familiar with it.[2]

Bacon's ideas about hearing are scattered in several different places among his writings. The most extended discussion is that in the second and third centuries of the *Sylva sylvarum* (1626), a work intended to demonstrate his method of compiling natural histories, which he describes as "a higher kind of natural magic." The distinctive qualities of natural magic, especially in Bacon's terms, were the emphasis on inductive rather than deductive logic and the assumption that nature's secrets could be discovered by the artificial manipulation of nature—that is, by experiment. In the *Sylva* Bacon reviews the subjects of musical consonance and music's effects on the mind and body, and then at great length proposes a series of investigations into questions concerning the physical propagation of sound. . . . Matters relating to the artificial manipulation of sound are tantalizingly raised, though not investigated, in a brief passage in the *New Atlantis*, which was published posthumously together with the *Sylva*.[3]

Helkiah Crooke's *Microcosmographia* of 1615 was the earliest English account of hearing treated from an anatomical perspective.[4] His theories about sound and hearing were based on works by some of the most important anatomists of the preceding century. In his description of the structure of the ear, for example, he referred to the work of Berengario da Carpi, Giovanni Filippo Ingrassia, Realdo Colombo, as well as Eustachio and Casserio.[5] For his account of sound he explicitly relied on Kaspar Bauhin's popular *Theatrum anatomicum*, directly borrowing several of Bauhin's illustrations.[6] Crooke regarded an understanding of the nature of sound as a necessary preliminary to the study of the ear, although "considering that to intreate of the manner of Hearing belongeth rather to a Phylosopher then to Anatomists, wee will be but briefe herein."[7] He also took up the question of why we are "recreated" by hearing.

Thomas Wright returned to England in 1595 under the protection of the Earl of Essex, whose entourage included Bacon. In 1597 he was made an honourable prisoner under the care of the

Dean of Westminster. During eight years of imprisonment, he was an active propagandist for the English Catholic cause. His *Passions of the Mind* was completed in 1598 and published in 1601. Wright wrote to Bacon saying that it contained nothing "either against this state or present religion." (None of his other writing in this period was so conciliatory.) The section on "How passions are moved with musicke and other instruments" was first included in the expanded second edition of 1604.[8] His theories became widely known in the course of the century, as can be seen from the fact that Robert Burton both relied on them for much of his explanation of the passions in his *Anatomy of Melancholy* and cited them explicitly.[9] In connection with hearing, of course, Wright's primary concern was the effect of music on the passions, but he does make glancing reference to the propagation of sound and its reception by the ear.

The Aristotelian idea that sound was produced by the striking of two bodies one against the other, carried through a medium to the ear, was a commonplace of sixteenth- and seventeenth-century physical thought. The analogy between the motion of sound and that of water waves, first used by the Stoics, was also widely used.[10] It should be emphasized, however, that this was strictly an analogy with the spread of ripples from a disturbance and that the precise way in which sound was like actual waves in water was not clarified until later in the seventeenth century with the work of Constantijn Huygens and Newton. Instead, most earlier writers followed Aristotle's notion of the transmission of the *species* of sound, that is, the concrete image thrown off by the sounding body.

Crooke, following Bauhin, does little more than accept these doctrines on authority, though he does argue against *De sensu* that "sound can be no motion."[11] Wright, too, merely transmits the Aristotelian view.[12] Bacon, on the other hand, while adding nothing in the way of theory, implicitly proposes that the classical ideas be regarded not as authoritative fact but as working hypotheses for an extensive programme of acoustical research. On the whole, Bacon's topics for investigation derive from the pseudo-Aristotelian *Problemata* and from Giambattista Della Porta's *Magia naturalis,* but he suggests particular experiments to be performed with musical instruments and other objects such as rods, buildings and so on.[13]

One of the most "profound secrets of nature" that Bacon thought his experimental method could discover effectively was the cause of musical "sympathy." Now known as sympathetic vibration, this was regarded in scholastic terms as an "occult" or mysterious phenomenon, in that its causes were not manifest to the senses and therefore not susceptible to physical explanation.[14] Natural magic, however, with its Neoplatonic and Stoic background, regarded sympathy in a broader sense as a fundamental explanation for many natural phenomena and therefore provided a more promising starting-point for Bacon's inquiry.

When a musical tone is produced by an instrument, a string on another instrument some distance away will respond to it, set in sympathetic motion. Bacon therefore considered that musical instruments would offer the best resource for empirical investigation into sympathy, in this case the powers and effects of musical sound on inanimate and animate bodies. The way he adopts musical instruments as experimental apparatus, so as to go beyond merely accepting music's effects in order to account for them, characterizes what he calls his "higher form of natural magic."

The theoretical framework for Bacon's approach to sympathetic resonance was a materialistic one. From a survey of his speculative writings it appears that Bacon developed a theory dividing all matter into the two categories: tangible and pneumatic substance. It was the interaction between these two types of matter that accounted for musical sympathy. He considered that all bodies of tangible matter were infused to a greater or lesser extent with a pneumatic substance or "spirit" of an airy, fiery nature. Inanimate bodies such as musical instruments would resonate

because the *species* of sounds, transmitted through the medium of air, mingled with their pneumatic parts.[15] Indeed, as we shall see below, Bacon accounted for music's power over the listener by a similar mechanism.

"The Just and Measured Proportion of the Aire Percussed, towards the Baseness or Treblenesse of Tones," wrote Bacon, "is one of the greatest Secrets in the Contemplation of Sounds."[16] He is the only one of the three earlier writers who deals with the question of musical consonance. He implicitly attacks the traditional Pythagorean theory of consonance as arising directly from ratios of small integers, declaring: "The cause [of the division of the octave] is dark, and hath not been rendred by any, and therefore would be better contemplated." On the one hand, he considers equal divisions into six whole tones or twelve semitones for purposes of discussion; on the other, he states that "harmony requireth a competent distance of notes."[17] In other words, he regarded the structure of the diatonic scale as arising from the requirements of art rather than being strictly natural in origin. . . .

By the early seventeenth century most of the macroscopic parts of the ear had been identified. This achievement was due to the activity of Italian anatomists, particularly those in Padua. What now came under debate was the role of the auditory ossicles, the location of the organ of hearing and how it presented images to the auditory nerve and thence to the brain.[18] Many authors, including Bacon and possibly Wright, held the Aristotelian view that the organ of hearing was the "internal air" of the middle ear. In the course of the seventeenth century, however, this explanation was replaced by others.

Crooke was one of the earliest writers to discuss an alternative view. He described the process of hearing in the following manner:

> The membrane being strucken doth move the three little bones and in a moment maketh impression of the character of the sound. This sound is presently received of the inbred Ayre, which it carryeth through the windowes of the stony bone . . . into the winding burroughs, and so into the labyrinth, after into the Snaile-shell, and lastly into the Auditory Nerve which conveyeth it thence unto the common Sense as unto his Censor and Judge. And this is the true manner of Hearing.[19]

. . . Crooke explained that the auditory nerves were joined in the bridge of the after-brain "from whence they proceed," which is why although there were two ears, sounds were "apprehended in one comprehension." For Crooke's purposes in this particular chapter, the sensation of hearing ended at the auditory nerve. The remainder of the section on hearing was concerned with "certain hard problems about the ears."[20]

Among these is the question of why we are "recreated" by hearing. Crooke claimed to follow the explanation in J. C. Scaliger's *Exotericae exercitationes:* "We learn things through the hearing more easily than through the sight, because the voice affects us more by inflection and insinuating itself into the sense."[21] Things that are heard, stated Crooke, make a deeper impression on our minds, and this is used in narration and action. This view goes back to Aristotle: "seeing, regarded as a supply for the primary wants of life, and its direct effects, is the superior sense; but for developing intelligence, and in its indirect consequences, hearing takes the precedence."[22] Crooke further appealed to the *Problemata* as an Aristotelian authority which stated that it is proportion which delights the senses and the mind. He explicitly rejected what he identified as the Platonic idea that the effects of music on the listener were a result of the instinctive harmony between the soul and music.[23] Continuing to follow Scaliger, he explained that music affects the listener because the spirits about the heart take in the trembling motion of the music and are stirred up.

These terms of debate belong to the doctrine of the passions, a theory of the mind which originated with Aristotle and, enriched with Neoplatonic elements, informed European thinking around 1600.[24] Wright's *Passions of the Mind* is a notable example of the genre in England. . . . As Wright expounds the doctrine, there were three types of actions of the soul: internal and immaterial actions of the wit and will; external and material actions of the senses; and the passions and affections which were between the reason and the senses, but which lay nearest to the senses. Although in one sense active, they are called passions "because when these affections are stirring in our minds, they alter the humours in our bodies, causing some passion or alteration in them." They might alter the mind or body in two ways—either as perturbations which troubled the soul, corrupted the judgement and seduced the will, thus leading to vice, or alternatively producing good when moderated by reason.[25]

Wright, following Aristotle, categorized the many different passions as either pleasureable or painful.[26] When an object was perceived by the imagination, the sensitive faculty signified to the soul whether or not the appetite should be followed. If it were "concupiscible" or pleasurable, it would be followed by the animal spirits flocking from the brain, the seat of the sensitive soul, via certain "secret channels" (the nerves) to the heart, the seat of the passions, which thereby became dilated. Conversely, an "irascible" or painful appetite led to the contraction of the heart and the gathering of "melancholy" blood around it, resulting in an imbalance of the humours and mental disquiet.[27] Reason, however, might always moderate the exaggerated effect of the passions.

The first step in this process, he thought, was to recognize the passions by outward motions of the body—in behaviour, dress, gesture, speech and manners. Music was one means by which the passions could be aroused and moderated (others, all linked to music by their mimetic function, included oratory, rhetoric and drama). Wright believed that although God must be worshipped through reason, the pleasure of the senses could still lead to devotion. Music could be used to elevate the mind to devotion, to prepare the spirit to receive prophecy and to lead to ecstasy. Although, on the other hand, music might also be used for dissolute levity and lead to debauchery, Wright argued that the fault was not in music itself, which was divine in origin, but in the weakness of mankind. The wickedness of musicians and the use of music for lascivious purposes did not diminish the noble status of music.[28]

Wright acknowledged four competing explanations for the power of music:

> The first is a certaine sympathie, correspondence, or proportion betwixt our soules and musick: and no other cause can be yeelded . . . The second manner of this miracle in nature, some assign and ascribe to God's general providence, who when these sounds affect the eare, produceth a certaine spirituall qualitie in the soule, the which stirreth up one or other passion, according to the varietie of voices or consorts of instruments . . . The third manner more sensible & palpable is this, that the very sound it selfe, which according to the best philosophie, is nothing else but a certaine artificiall shaking, crispling or tickling of the ayre . . . which passeth thorow the eares, and by them unto the heart, and there beateth and tickleth it in such sort, as it is moved with semblable passions . . . The last and best manner I take to be, that as all other sences have an admirable multiplicitie of objects which delight them, so hath the eare . . . so in musicke, divers consorts stirre up the heart, divers sorts of joyes, and divers sorts of sadness or paine. . .[29]

Wright lends his weight to the disappointingly tautological last hypothesis, but the first and third theories he mentions served as a useful point of departure for Bacon. Bacon regarded the soul's response to music as a variety of sympathy extremely similar to the sympathetic resonance of musical instruments, since it likewise depended on the interaction between tangible and

pneumatic substance, in this case, *spiritus*. For Bacon, the *spiritus* was the instrument of the incorporeal, rational soul. Suffused throughout the body, it was identical to the sensible or lower soul in animals. Among its many tasks, it was responsible for sensory and motor functions and the activities of the imagination. The *species* of sound mingled with the *spiritus* in the ear, which immediately perceived whether it was pleasurable or painful. Pleasing musical sounds were produced by regularity and proportion, and equality of the "parts" or "pores" of the sounding body which forced the air into the same posture or figure. The *spiritus* then carried the sound to the brain, the seat of the common sense, memory and imagination, which induced a physical response in the heart and body.[30] Although this has many similarities to Wright's doctrine of the passions, it can be seen to be different in detail.

Bacon thus explained the effects of music on the spirits in the *Sylva:*

> It hath beene anciently held, and observed, that the *Sense of Hearing*, and the *Kindes of Musicke*, have most Operation upon *Manners;* . . . The *Cause* is, for that the *Sense of Hearing* striketh the *Spirits* more immediately, than the other *Senses;* And more incorporeally than the *Smelling* . . . Harmony entring easily, and Mingling not at all, and Comming with a Manifest Motion; doth by Custome of often affecting the *Spirits*, even when the Object is removed. And therefore wee see, that *Tunes* and *Aires*, even in their owne Nature, have in themselves some Affinity with the *Affections* . . . So as it is no Marvell, if they alter the *Spirits* themselves . . . Wee see also that severall *Aires*, and *Tunes*, doe please severall *Nations*, and *Persons*, according to the Sympathy they have with their *Spirits*.[31]

Bacon's use of the same mechanism to account for sympathetic vibration and for music's effect on the listener shows that for him these were not separate issues but aspects of a single problem. In his case, this might be identified as the nature of sound. Crooke the anatomist, as we have seen, considered his province to be "certain hard problems about the ears," while Wright, whose principal concern was religious, placed his most general questions about hearing in the section on "Problems concerning the substance of our Soules." But allowing for differences of emphasis, each of the three writers in fact addressed the same issues.

Wright may have thrown up his hands, saying: "God only knows who can answer these questions," but the problems he posed include:

> What is the faculty of hearing, where it resideth, and what is the object? . . . What is the Echo? . . . By what manner is it made? . . . Why do we heare better by night than by day? . . . Why does the fyling of iron grind some men's teeth? . . . For what reason corporall Musicke and consortes of Instruments so ravish and abstract a spirite, a soul, transporting it almost into a Paradise of joy? . . .[32]

Crooke at least attempted to answer the questions *he* posed, though he explicitly relied on earlier authorities. Bacon's treatment of sound and hearing in the *Sylva* was still more sophisticated, being framed as a programme of experiments linked to problems not unlike those of Wright and Crooke. . . .

Descartes transformed the structures of intellectual discourse in the later seventeenth century. He himself abandoned the Aristotelian method of starting from a series of questions, replacing it with a method derived from Euclid based on axioms. This involved an emphasis on deductive logic which ran counter to the inductive tendencies observable in Bacon, for example. Descartes's system of natural philosophy was radically unified; his account of all phenomena started from the same axioms. In essence, these were: first, that everything except mind (unique to man, higher creatures and God) is inert matter devoid of any innate source of activity; and second, that all

phenomena are to be explained in terms of the behaviour of passive particles of matter moving either inertially or as a result of the impulse of other particles in motion.

The equation of matter with extension meant that Descartes could conceive of the universe as a *plenum* filled with infinitely divisible matter, which was effectively made up of three types. The first of these comprised large, irregular particles of "gross matter" which formed solid bodies; the second consisted of smaller but still coarse spherical particles of air (which provided, among other things, the medium of sound); the third was made up of extremely fine particles which filled the spaces between the first and second types and was called "subtle matter." All phenomena in nature were to be explained as necessary consequences of this matter in motion, in terms of familiar mechanisms. From the irreducible, simple properties of extension, figure and motion, the physical world could be reconstructed and made clear to the reason.[33]

Descartes's idea of the wave motion of sound can be outlined as follows. A sounding body communicates a series of impulses or pressures through the medium, which are directed radially away from its centre. These impulses strike larger objects, including the eardrum, as a series of little "shocks." The motion striking the organ of hearing is transmitted directly through the eardrum, the auditory ossicles and the air of the inner ear to the outer end of the auditory nerve.

Descartes's detailed description of the structure of the nerves is essential to his explanation of how sound is transmitted to the brain and thence to the rest of the body. Nerves were small tubes divided into branches like veins and arteries. Within these were extremely thin filaments like taut strings, which instantaneously transmitted motion from the extremities to the brain. Here they opened certain pores, releasing "animal spirits" which ran along the same tube and inflated the innervated muscles, causing instantaneous motion. Descartes's account was essentially a recasting of Galen's views in mechanical terms. Passions were still explained in terms of the animal spirits moving towards and away from the heart, and this was effected by the imagination, an instrument of the soul.[34]

Descartes thought that, just as the effects of musical sound on man could be explained in terms of motion, so could those on inanimate objects. He followed Galileo and Mersenne in his treatment of sympathetic resonance. . . .

Mersenne and Galileo were the first to establish that the pitch produced by a musical string is determined by the frequency of its vibrations: the greater the frequency, the higher the pitch. By 1635 Mersenne had demonstrated how frequency depends on the length, tension and thickness of a string. (Frequency is inversely proportional to length and to the square root of thickness, and directly proportional to the square root of string tension.) Consonance could now be explained in quantitative terms. A single musical tone is produced by a regular succession of vibrations or small shocks transmitted from the string through the air to the drum of the ear. The pulses of two notes striking the eardrum are perceived as consonant if they coincide regularly. The more frequently the pulses coincide with each other, the more consonant the interval.[35]

The basic principles of the "coincidence theory" of consonance, as it is now called, are outlined by Descartes in the following manner:

> A single . . . blow will be able to cause nothing but a dull noise which ceases in a moment and which will vary only in being more or less loud according as the ear is struck with more or less force. But when many blows succeed one another, as one sees in the vibrations of strings and of bells when they ring, then these little blows will compose one sound which the soul will judge smoother or rougher according as the blows

> are more or less equal to one another, and which it will judge to be higher or lower according as they succeed one another more promptly or tardily, so that if they are half or a third or a fourth or a fifth more prompt in following one another, they will compose a sound which the soul will judge to be higher by an octave, a fifth, a fourth, or perhaps a major third, and so on. And finally, several sounds mixed together will be harmonious or discordant according as more or less orderly relations exist among them and according as more or less equal intervals occur between the little blows that compose them.[36]

According to this theory, the most pleasing interval is the unison, in which all the pulses or blows of the notes coincide. The octave, with a frequency ratio of 2:1, is next in order, followed by the fifth 3:2, and so on. Dissonant and non-musical sounds are produced by irregularly related pulses striking the ear.

Musical sound, as an abstract single tone or as a combination of two notes, thus seemed to provide a perfect demonstration of the real, *mathematical* correspondence between the external world of particulate motion and the mind, which can grasp abstract relationships. The conjunction of mathematics and physics was one of the most distinctive contributions of the mechanical philosophy. The unique attraction of the coincidence theory was that it could be shown to the eye and (apparently) objectively verified by the ear.

The power of the Cartesian synthesis (for those who adopted it) was that it explained everything at once—in twentieth-century terms, it was a "grand unified theory." Its weakness was expressed by Descartes himself: "I would like people to think that, if what I have written . . . on any . . . matter that I have treated in more than three lines in my printed works, appears to be wrong, all the rest of my Philosophy is worthless."[37] All three of our later seventeenth-century English writers on hearing, Digby, Willis and Hooke, attacked Descartes in detail; but such was the strength of the mechanical philosophy that all three accepted its fundamental premise that matter and motion are the basis of explanation, however different their particular theories may have been.

Kenelm Digby was a Catholic royalist who had lived in self-imposed exile in Paris from 1643. Digby was one of the first English authors to promote the corpuscularian principles of the mechanical philosophy. In 1644 he published *Two Treatises: In the One of which the Nature of Bodies; in the Other, the Nature of Man's Soule; is Looked Into* in order to demonstrate that all actions of bodies could be explained by motion of one form or another. Such actions need not be accounted for by any intervention of the soul, which, he claimed, must be incorporeal. (This was important to Digby because it offered a means of reconciling doctrinal differences between English Catholics and their Anglican counterparts.)[38] Digby's treatment of all the topics related to hearing which we have isolated tends to demonstrate atomistic ideas within an Aristotelian framework. It is noticeable that he is the earliest of the English writers considered here who found it necessary to deal with the problem of aural memory.

Digby's understanding of the propagation of sound was consistent in its essentials with the Cartesian explanation, itself differing only in minor details from classical tradition:

> [Sound] is nothing else, but an undulation of the ayre, caused by the smart and thicke vibration of the corde, . . . and so, when it breaketh out of the instrument . . . , it causeth the same undulation in the whole body of ayre round about.[39]

But Digby parted company with Aristotle's theory of the internal air as the organ of hearing and with Descartes's explanation of how sound is transmitted from the ear to the brain as motion

through the nerves, for "if there were no more, but an actuall motion, in the making of hearing; I do not see, how sounds could be conserved in the memory, since of necessity, motion must alwayes reside in some body."[40]

He argues that if vibration alone could account for the transmission of sound to the brain, the eardrum would be the only essential part of the ear. But the organ is more complex:

> There is a hammer and an anvile: whereof the hammer, stricking upon the anvile, must of necessity beate off such litle partes of the brainy steames, as flying about do light and sticke upon the toppe of the anvil, these by the trembling of the ayre following its course, can not misse of being carried up to that part of the braine, where unto the ayre within the eare is driven by the impulse of the sound: and as soon as they have given their knocke, they rebound backe again into the celles of the brain fitted for harbours to such winged messengers: where they remaine lodged in quietnesse, till they be called for againe, to renew the effect which the sound did make at the first. . . .[41]

. . . Digby accepted Descartes's model for the effect of sounds on the passions, allowing for his different view of nerve action. Like earlier writers, he saw pleasing effects as dilating the heart and unpleasant ones as causing its contraction. But he rejected the simple reduction of the passions into the two categories of pleasure and pain, since the stimuli of vision and hearing were generally more complex. As far as he could see, this complexity was caused by association of memories: "for the most part, the objects of these two nobler senses, do move us, by being joined in the memory with some other thing that did eyther please or displease some of the other three senses."[42]

Thomas Willis was appointed Sedleian Professor of Natural Philosophy in Oxford in 1660. He was a medical practitioner whose writings are chiefly concerned with anatomy. The principal source for his theory of sound is contained in *De anima brutorum;* he had addressed the question of musical memory in *Cerebri anatome.*[43] The distinctive difference of Willis from Descartes is that, whereas the latter regarded the nature and effects of sound as entirely physical (that is, arising from the transmission of motion among particles), the former took sound and its effects to be essentially chemical, arising from the action of one substance on another.

Willis's understanding of sound transmission therefore differs considerably from any we have seen so far. Although he, like the mechanical philosophers, assumed matter to be particulate, he rejected the atomistic theory as being "too remote from sense," preferring instead to explain physical phenomena in iatrochemical terms. He recognized five elements: spirit, sulphur, salt, water and earth, arranged from the most active to the most passive.[44] Willis thought air (which was for him compound and not elemental) contained "sonorous particles" that could be impressed with "audible species" by a sounding body and would then communicate the species to the ear by a wave motion. He suspected these particles to be saline in nature, since "the particles of this element are most of all moveable & active."[45]

Willis gives a very complete and circumstantial account of the role played in hearing by all of the anatomical elements of the ear. The three most important parts were the eardrum, the "implanted air" of the middle ear and the cochlea or "labyrinth." Willis believed that the role of the auditory ossicles was to control the tension of the eardrum according to the loudness of the sound received. In contrast to the Aristotelian notion of the "inward air" as the effective organ of hearing, he regarded it as merely transmitting the sound to the *fenestra ovalis* or window into the cochlea, "which is properly the organ of hearing." . . .

He observed that the cochlea was divided into two parts by the basiliar membrane and could therefore be considered a twofold organ of hearing. This, he suggested, was to prevent confusion between sounds which were heard simultaneously and yet perceived separately.

Willis understood nerve action as a flow of "animal spirits." This led him to a very clear conception of the way the "ideas of sounds" were stored in the memory. He regarded memory as having two "distinct Store-houses": the brain proper, or cerebrum, "which is the Chest of Memory acquired as it were artificial," and "the Cerebel, which is the place of natural memory." The audible impulse is carried by the animal spirits along the nerves to the "common Sensory, . . . and being also delivered to the Brain, stirs up the Imagination, and so leaves in its Cortex an image or private mark of itself for the Memory." Willis thought that the ideas of sounds were carried to the cerebellum by the same spirits, "which forming there footsteps or tracts, impress a remembrance of themselves."[46]

This allowed him to give a very plausible explanation of why some people are able to memorize and perform music more readily than others "without any meditation or labour of the Brain":

> . . . in all, the audible Species go to the Cerebel sooner and more immediately than the Brain; yet in some the Cerebel being harder, and not easily yielding to the received impressions, those Species, because they could impress nothing of themselves in their passing to the Cerebel, being carried towards the common Sensory, leave their Types or Ideas chiefly and almost wholly in the Brain: which part being still busied with disturbed motions, is less apt to keep distinctly the composures of Harmony. But in the mean time, in others the Species of audible things, besides that they are carried to the common Sensory and to the Brain, do also affect the Cerebel, especially if they are harmonically figured . . . with a peculiar order and Scheme of the animal Spirits: where, as the Species of the Harmony being disposed in convenient little places and cells are kept, afterwards they flow out from thence, almost unthought of, without any endeavour or labour of remembrance, but in a distinct series, and as it were in composed modes and figures, and so by blowing up the vocal processes, they consitute sweet Tunes and vocal Musick.[47]

Willis also looked into the question of "wherefore Musick does not only affect the Phantasie, with a certain delight, but besides cheares a sad and sorrowful Heart, yea allays all turbulent passions excited in the breast from an immoderate heat and fluctuation of the blood." When "the animal Spirits . . . transfer the force of their Affections" to the heart, "the Melody introduced to the Ears, . . . does as it were inchant with a gentle breath the spirits there inhabiting, and composes them, called off from their fury, to numbers and measures of dancing, and so appeases all tumults and inordations therein excited."[48] . . .

Robert Hooke was Willis's assistant at Oxford in the mid-1650s before working on the air pump with Robert Boyle and became Curator of Experiments for the early Royal Society in 1663. He is not generally recognized as a speculative thinker as well as a strict experimentalist, yet it is clear from both his published and unpublished writings that he held a general theory of matter based on principles of sympathy and antipathy, in which all particles related to one another in terms of harmonic vibration. The first work in which he elaborates this notion at length is the *Micrographia,* which contains a crucial discussion of musical consonance.[49] . . .

Hooke held a superficially traditional wave theory of sound, but it occupied a unique place in his cosmology thanks to his assumption that "God always acts geometrically by due proportion of number, weight and measure." . . .

Because Hooke believed that "Nature acts regularly and geometrically in all sensible and insensible motions," he was able to use the measurable properties of sounding or vibrating bodies to account for other properties including elasticity or spring, gravity and magnetism. The "sympathy" among all these phenomena was an idea that he appropriated from the tradition of natural magic and was one of Hooke's most important contributions to the thinking of Newton.[50]

Hooke sets forth only the most important aspects of his understanding of the relation between the structure of the ear and its reception of sound:

> . . . it has a most curious, neat contrivance of a small film which is soe expos'd to the air that it is capable of being mov'd by it. Nor is it only like the bare head of a drum, but there is a further excellency in its fabrick, and that is this: that by means of several little bones, nerves & muscles, it can be soe tuned, as it were, or stretch'd, that it becomes harmonicall or unison to whatsoever sound is heard.[51]

. . . The ear was capable of perceiving only certain pitches, since vibrations which were too slow would not be able to move the eardrum, while too rapid vibrations would produce pain since the eardrum was overtightened, like a string tuned too high above its natural pitch.

This further accounts for Hooke's explanation of musical consonance, a subject not entered into in detail by Digby or Willis. He distinguishes musical sounds from noise by the way they affect the eardrum:

> Noise is displeasing because the ear cannot keep up with the constant change of tuning required, whereas the regularity of musical tones is easier and therefore more pleasant.

Following the coincidence theory of consonance, Hooke held that harmony transcended the melodic and rhythmic aspects of music,

> affording the acustick faculty the most pleasant titillation & most ravishing pleasure & delight of all. And the reason of it is clear: for the Eare, being tun'd to either of the notes struck together in concord, is likewise regularly moved with a pleasing variety, there being on all harmonaous notes a coincidence of the Vibrations.[52]

He wrote in numerous places about the proportionality of consonance, and indeed this aspect of musical harmony served him as a model for all of the harmonies he observed in the universe.

Hooke also scattered his observations about the effects of music on the mind and body in several of his writings, and it is notable that he never discusses them in terms of the medical theory of the passions. He does say that "time" or rhythm "certainly is the very spirit of Musick, and that which is the most active and operative upon the affections & passions of men." However, his description of how quick time "rouses & quickens the spirits & facultys of the hearer" and slow time makes the spirits "thereby dull, sottish & heavy" depends not on the flow of spirits to the heart but rather on the rate at which the "Acustick faculty. . . [is] exerciz'd in tuning the Eare." . . .

There is an important difference between the two groups of writers studied here. With the earlier group, Bacon, Crooke and Wright, it seemed best to examine their ideas topic by topic, but with Digby, Willis and Hooke it proved necessary to discuss them writer by writer. The reason for this is the much greater degree of integration found in the later explanations of hearing: all the aspects of Digby's theory depend on his understanding of memory, all those of Willis's on his iatrochemical premises, all those of Hooke's on his notion of all matter as vibrating. Each of these theories of hearing is an integral part of a much larger system of natural philosophy.

In contrast, the ideas of Crooke and Wright are less closely connected. Crooke indeed may have said that a knowledge of the nature of sound is necessary to understand the workings of the ear, but neither he nor Wright was able to refer all questions concerned with hearing to a single system of explanation. Each of their theories is *consistent* rather than *coherent;* that is, while its various aspects do not contradict one another, neither do they coalesce into a single complex idea.

Bacon stands out as the one early seventeenth-century English writer who thought that theories ought to be unified. Joining the intellectual traditions of natural philosophy and natural magic, he sought a central explanation for many phenomena (emphatically including all those connected with hearing) in the notion of "sympathy." He recognized that he was not able to explain what sympathy was and proposed instead a programme of experiment to discover it. Bacon regarded his own work as preparatory to the grand unified theory which he considered the goal of experimental philosophy. It was Hooke who took a decisive step, assembling Bacon's idea of sympathy, the mechanical theory of sympathetic vibration in musical instruments and his own notion that the fundamental particles of matter are constantly vibrating, to account for the rationality he observed in the universe at large.

Bacon had urged that natural philosophy should be radically integrated; Descartes showed that it could be done. Instead of resting the authority of his philosophy on the weight of earlier authors, he expressly based it on the coherence of each part with every other. English writers on hearing in the later seventeenth century rejected one or another of Descartes's assumptions (and thereby his theory as a whole), but they implicitly accepted his most fundamental premise: that every aspect of their theories must fit together as neatly as possible. Digby, Willis and Hooke, each in his own way, achieved an elegance of theory that is absent from the writings of Crooke and Wright, as well as an explanatory power that Bacon never realized.

Notes

1 For an introduction to ancient theories of hearing see A. Politzer, *Geschichte der Ohrenheilkunde,* second edition (Stuttgart, 1913), I, pp. 1–30; J. I. Beare, *Greek Theories of Elementary Cognition from Alcmaeon to Aristotle* (Oxford, 1906), pp. 93–130; D. W. Hamlyn, *Sensation and Perception: A History of the Philosophy of Perception* (London, 1961), pp. 1–43; for music therapy see B. Meinecke, "Music and Medicine in Classical Antiquity" in *Music and Medicine,* edited by D. M. Schullian and M. Schoen (New York, 1948), pp. 47–95, and G. E. R. Lloyd, *Magic, Reason and Experience* (Cambridge, 1979), pp. 42–3.

2 Biographical information on Francis Bacon is widely available; see, for example, the article by T. Fowler in *Dictionary of National Biography,* s.v. For biographical details of Crooke, see W. Munk, *The Roll of the Royal College of Physicians in London,* second edition (London, 1878), I, p. 177; G. Clark, *A History of the Royal College of Physicians in London* (Oxford, 1949), I, pp. 187, 204–5, 251, 258, 277; G. Keynes, *The Life of William Harvey* (Oxford, 1966), pp. 72–6; P. Allderidge, "Management and Mismanagement at Bedlam, 1547–1633" in *Health, Medicine and Mortality in the Sixteenth Century,* edited by C. Webster (Cambridge, 1969), pp. 141–64 (154–63). For a biography of Wright, see T. A. Stroud, "Father Thomas Wright: A Test Case for Toleration," *Biographical Studies 1534–1829,* I (1951), pp. 189–219.

3 For the sources described, see F. Bacon, *The Works,* edited by J. Spedding, R. L. Ellis and D. D. Heath (London, 1857), II, pp. 331–680 (*Sylva*); III, pp. 125–68 (*New Atlantis:* section on "sound houses," pp. 162–3) and pp. 655–80 (*De sono*). On Bacon's natural magic, see P. Rossi, *Francis Bacon: From Magic to Science,* translated by S. Rabinovitch (London, 1968); on his musical ideas see P. M. Gouk, "Music in Francis Bacon's Natural Philosophy" in *Francis Bacon: terminologia e fortuna nel XVII secolo,* edited by M. Fattori (Rome, 1985), pp. 139–54.

4 Helkiah Crooke, *Microcosmographia* (London, 1615), pp. 573–612 on the ear's structure, pp. 691–701 on hearing and "problems about the ears."

5 Berengario da Carpi gave the first recorded description of the malleus and incus in his *Commentaria super anatomia Mundini* (Bologna, 1521); according to Gabriele Fallopio's *Observationes anatomicae* (Venice, 1561), a description

of the stapes was first made in 1546 by Giovanni Filippo Ingrassia (c. 1510–80), but his work was only published posthumously as *In Galeni librum de ossibus* (Palermo, 1603). Works by the other anatomists referred to by Crooke include R. Colombo, *De re anatomica* (Venice, 1559); B. Eustachio, *Opuscula anatomica* (Venice, 1563), particularly the *Epistula de auditus organis* and G. Casserio, *De vocis auditusque organis historia anatomica* (Ferrara, 1600; second edition, 1601) and his *Pentaestheseion, hoc est De quinque sensibus liber* (Venice, 1609).

6 Compare Crooke, *Microcosmographia,* Tabula IV, p. 575, with K. Bauhin, *Theatrum anatomicum* (Frankfurt, 1605), Tabula XXII, facing p. 790. Also, Crooke's Tabula X, p. 577 corresponds with Bauhin's Tabula XXIV facing p. 810.

7 Crooke, *Microcosmographia*, p. 609.

8 The relevant sections of T. Wright, *The Passions of the Mind,* second edition (n.p., 1604) include pp. 104–48: "How passions may be discovered"; pp. 149–293: "Wherein are delivered the means to move passions," especially pp. 159–72: "How passions are moved with music and instruments"; and pp. 300–8: "Problems concerning the substance of our Soules," especially, pp. 307–8: "Concerning Hearing."

9 R. Burton, *The Anatomy of Melancholy* (Oxford, 1621), p. 34 (pt. 1, section 1).

10 For a general introduction to the subject see F. V. Hunt, *Origins in Acoustics: The Science of Sound from Antiquity to the Age of Newton* (New Haven and London, 1978). On sixteenth-century Italian theories see C. V. Palisca, *Humanism in Italian Renaissance Musical Thought* (New Haven and London, 1985), pp. 50–60, 230–2, 238–9, 254–9; and for seventeenth-century ideas see G. L. Finney, *Musical Backgrounds for English Literature: 1580–1640* (New Brunswick, 1962), pp. 139–58; A. E. Shapiro, "Kinematic Optics: A Study of the Wave Theory of Light in the Seventeenth Century," *Archive for the History of the Exact Sciences,* 11 (1973), 134–266 (135–41) and P. M. Gouk, "Music in the Natural Philosophy of the Early Royal Society," (Unpublished PhD dissertation, University of London, 1982), pp. 25–73: "Changing Theories of Sound in Seventeenth Century England."

11 Crooke, *Microcosmographia,* p. 693.

12 Wright, *Passions,* p. 170.

13 Material used by Bacon from the *Problemata* includes, for example, XI.5 ("Why are sounds more audible at night?"); XI.37 ("Why is it easier to hear sounds from outside in a house than those from inside a house outside it?") and XI.45 ("Why is it that though the voice, since it is a kind of stream, is naturally inclined to travel upwards, yet it is more audible below from above than above from below?").

14 On the changing definition of the term "occult" see K. Hutchinson, "What Happened to Occult Qualities in the Scientific Revolution," *Isis,* 73 (1982), pp. 233–53; and J. Henry, "Occult Qualities in the Experimental Philosophy: Active Principles in Pre-Newtonian Matter Theory," *History of Science,* 24 (1986), pp. 335–81.

15 Bacon, *Sylva,* experiments 801, 835. On Bacon's ideas on matter and spirits see D. P. Walker, "Francis Bacon and Spiritus" in *Science, Medicine and Society in the Renaissance,* edited by A. G. Debus (New York, 1972), II, pp. 121–30, reprinted in his *Music, Spirit and Language in the Renaissance,* edited by P. M. Gouk (London, 1985); G. Rees assisted by C. Upton, *Francis Bacon's Natural Philosophy: A New Source* (Chalfont St. Giles, 1984), especially pp. 33–62.

16 Bacon, *Sylva,* experiment 183.

17 Ibid., experiments 103, 108.

18 Politzer, *Ohrenheilkunde* I, pp. 73–159; F. J. Cole, *History of Comparative Anatomy from Aristotle to the Eighteenth Century* (London, 1944), pp. 76, 96, 110–25; C. D. O'Malley and E. Clarke, "The Discovery of the Auditory Ossicles," *Bulletin of the History of Medicine,* 35 (1961), pp. 419–41; A. C. Crombie, "The Study of the Senses in Renaissance Science," *Proceedings of the 10th International Congress for the History of Science, Ithaca, 1962* (Paris, 1964), I, pp. 93–117 (99–100).

19 Crooke, *Microcosmographia,* p. 696.

20 Ibid., pp. 698–700.

21 J. C. Scaliger, *Exotericarum exercitationum liber XV de subtilitate, ad Hieronymum Cardanum* (Paris, 1557), f. 369^{r} (Ex. 298.1). This work was published as a reply to G. Cardano, *De subtilitate libri XXI* (Lyons, 1554); in book XIII: "De sensibus sensibilibusque ac voluptate," Cardano discusses hearing and the effects of music (pp. 488–94), while in book XVIII: "De mirabilibus" (pp. 726–7), he deals with the sympathetic motion of strings. Scaliger's *Exercitationes* responds to these questions in the following passages: ff. 366^{r}–368^{v} (Ex. 297); ff. 368^{v}–369^{r} (Ex. 298.1); f. 370^{r-v} (Ex. 298.5); ff. 381^{r}–383^{r} (Ex. 302); ff. 453^{r}–457^{r} (Exx. 344 and 345). See also I. Maclean, "The Interpretation of Natural Signs: Cardano's *De subtilitate* versus Scaliger's *Exercitationes*" in *Occult and Scientific Mentalities in the Renaissance,* edited by B. Vickers (Cambridge, 1984), pp. 231–52.

22 Aristotle, *De sensu* 1, 437^{a}4–6.

23 Pseudo-Aristotle, *Problemata* XIX.38 and 39.

24 English accounts of the power of music, rhetoric and poetry to affect the passions are found in works such as the anonymous *Praise of Music* (London, 1586), John Case's *Apologia musices* (London, 1588), George Puttenham's *Art of English Poesie* (London, 1589) and Thomas Campion's *Observations on the Art of English Poesie* (London, 1602).

25 Wright, *Passions,* pp. 7–11 (8).

26 Ibid., p. 24.
27 Ibid., p. 45.
28 Ibid., pp. 104–48; 159–72.
29 Ibid., pp. 168–71 (wrongly paginated as 117).
30 *Sylva*, experiments 101–3, 128, 168.
31 *Sylva*, experiment 114.
32 Wright, *Passions*, pp. 307–8.
33 For an introduction to and bibliography on Descartes's scientific ideas and methodology see A. C. Crombie, M. S. Mahoney and T. M. Brown, "René du Perron Descartes" in *Dictionary of Scientific Biography*, edited by C. C. Gillispie (New York, 1971), IV, pp. 51–65.
34 A concise summary of Descartes's theory of sound transmission, hearing and the perception of consonance is found in H. F. Cohen, *Quantifying Music: The Science of Music at the First Stage of the Scientific Revolution, 1580–1650* (Dordrecht, 1984), pp. 172–5. Descartes first outlined his theory of sense perception in *La Dioptrique* (1637), discours 4, but the most extensive account is found in *Traité de l'homme* (drafted in the early 1630s and published in 1664); translated by T. S. Hall: R. Descartes, *Treatise on Man* (Cambridge, Mass., 1972), pp. 45–8. See also J. C. Kassler, "Man—A Musical Instrument: Models of the Brain and Mental Functioning before the Computer," *History of Science*, 22 (1984), pp. 59–92 (62–6).
35 On Mersenne see R. Lenoble, *Mersenne, ou la naissance du méchanisme* (Paris, 1943; reprinted 1971) and *Dictionary of Scientific Biography*, IX, pp. 316–22. For a summary of his work on acoustics and the coincidence theory see also Hunt, *Origins in Acoustics*, pp. 82–100, and Cohen, *Quantifying Music*, pp. 97–114.
36 Descartes, *Treatise on Man*, p. 47.
37 Letter of Descartes to Mersenne 4 March 1630; translation from Cohen, *Quantifying Music*, p. 171.
38 J. Henry, "Atomism and Eschatology: Catholicism and Natural Philosophy in the Interregnum," *British Journal of the History of Science*, 15 (1982), pp. 211–39.
39 Kenelm Digby, *Two Treatises* . . . (Paris, 1644), p. 256 ("On Bodies").
40 Ibid., p. 279.
41 Ibid.
42 Ibid., pp. 295–6.
43 T. Willis, *De anima brutorum quae hominis vitalis ac sensitiva est, exercitationes duae* (Oxford, 1672), pp. 189–202 ("De sensu auditus"), translated as *Two Discourses Concerning the Soul of Brutes* in T. Willis, *The Remaining Medical Works* (London, 1683; reprinted Gainesville, 1971), pp. 69–74 ("Concerning the sense of hearing"; and his *Cerebri anatome: cui accessit nervorum descriptio et usus* (London, 1664), pp. 211–15, translated as *The Anatomy of the Brain and Nerves* in *The Remaining Medical Works* (London, 1681; reprinted Montreal, 1965), pp. 116–21, 141–5.
44 Willis's iatrochemical theories were first expounded in the *Diatribae duae medico-philosophicae, quarum prior agit de fermentatione* (London, 1659). See also T. S. Hall, *Ideas of Life and Matter: Studies in the History of General Physiology 600 BC–1900 AD* (Chicago, 1969), I, pp. 312–25; J. R. Partington, *History of Chemistry* (London, 1961), II, pp. 304–10.
45 Willis, *Two Discourses*, p. 70.
46 Willis, *Anatomy of the Brain*, p. 118.
47 Ibid., p. 119.
48 Ibid.
49 R. Hooke, *Micrographia* (London, 1665), pp. 15–16. [See also] "A Curious Dissertation" [in] MS London, The Royal Society Library, Classified Papers, vol. 2, no. 1, and . . . transcribed in P. M. Gouk, "The Role of Acoustics and Music Theory in the Scientific Work of Robert Hooke," *Annals of Science*, 37 (1980), pp. 573–605. The "Musick Scripts" and "Preaching Lecture" are in MSS Cambridge, Trinity College, MSS O.11a.1[11–12] and O.11a.1[14F–H]; these are discussed in J. C. Kassler and D. R. Oldroyd, "Robert Hooke's Trinity College 'Musick Scripts,' his Music Theory and the Role of Music in his Cosmology," *Annals of Science*, 40 (1983), pp. 559–95. The lecture on memory, the full title being "An Hypothetical Explication of Memory; how the Organs made Use of by the Mind in its Operation may be Mechanically Understood," is published in R. Hooke, *The Posthumous Works*, edited by R. Waller (London, 1705), pp. 138–48; see also B. R. Singer, "Robert Hooke on Memory, Association and Time Perception," *Notes and Records of the Royal Society*, 31 (1976), pp. 115–31.
50 Newton was able to model mathematically the propagation of sound by the alternate compression and rarefaction of the air (the currently accepted theory) because he visualized the air as made up of particles which oscillated backwards and forwards like little pendulums, an idea likely to have been derived from Hooke; even more direct was Hooke's influence on Newton's theory of colour, which he revised after Hooke raised objections. See C. Truesdell, "The Theory of Aerial Sound 1687–1788" in L. Euler, *Opera omnia*, second series (Lausanne, 1955), XIII, pp. xix–xxix; S. Dostrovsky, "Early Vibration Theory: Physics and Music in the Seventeenth Century," *Archives for the*